NASA TECHNICAL
MEMORANDUM

Report No. 53848

THE TEMS APOLLO-SATURN V TRACKING SYSTEM ERROR MODEL RESULTS THROUGH THE AS-504 FLIGHT TEST

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June 5, 1969

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM X-53848		

4. Title and Subtitle	5. Report Date
The TEMS Apollo-Saturn V Tracking System Error Model Results Through the AS-504 Flight Test	June 5, 1969
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Bobby G. Junkin	
9. Performing Organization Name and Address	10. Work Unit No.
George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared by Computation Laboratory
Science and Engineering Directorate

16. Abstract

This report presents the Apollo-Saturn V truncated C-Band radar tracker error model results obtained on the AS 501-504 flight tests. It is shown that the coefficient standard deviation of the azimuth servo lag error model term for the Bermuda Radars is significantly less than the values obtained for the Cape and Grand Bahama Radars. The error model terms with the highest frequency of occurrence are found to be the servo lag terms in azimuth and elevation, and the scale factor and timing delay terms in range.

17. Key Words	18. Distribution Statement
	Public Distribution Bobby G. Junkin

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	51	$3.00

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DEFINITION OF SYMBOLS

Symbol	Definition
TEMS	Acronym for Tracking System Error Model Studies
ΔR, ΔA, ΔE	Functional expressions for the systematic errors in range, azimuth, and elevation, respectively
C_0, C_1, ...	Coefficients in range error model
D_0, D_1, ...	Coefficients in azimuth error model
F_0, F_1, ...	Coefficients in elevation error model
$\dot{R}$, $\dot{A}$, $\dot{E}$	First derivatives of range, azimuth, and elevation, respectively, with respect to time
$\ddot{A}$, $\ddot{E}$	Second derivatives of azimuth and elevation, respectively, with respect to time
X, Y, Z	Reference position of vehicle in an earth-fixed ephemeris coordinate system with origin at the tracking site
σ^2_{VR}, σ^2_{VA}, σ^2_{VE}	Least square residual variances in range, azimuth, and elevation, respectively
F Level	Ratio for determining the statistical significance of a regression equation
σ_Y	Standard deviation of the response variable

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SUMMARY

This report presents the Apollo-Saturn V truncated C-Band radar tracker error model results obtained on the AS 501-504 flight tests. It is shown that the coefficient standard deviation of the azimuth servo lag error model term for the Bermuda Radars is significantly less than the values obtained for the Cape and Grand Bahama Radars. The error model terms with the highest frequency of occurrence are found to be the servo lag terms in azimuth and elevation, and the scale factor and timing delay terms in range.

INTRODUCTION

This report is one in a continuing series summarizing results from the evaluation of tracking system measurement errors on the Apollo-Saturn V flight tests. The results in the previous TEMS report [1] and the current AS-504 results are summarized and presented herein. The TEMS Multiple Regression Analysis Method [2] is used in the evaluation process for obtaining the AS-504 results. Truncated error model expressions to describe the established tracker errors are determined by utilizing the TEMS method in conjunction with a stepwise regression procedure. The basic error model equations used in the analysis are given by the following:

Range

$$\Delta R = C_0 + C_1 R + C_2 \dot{R} + C_3 t + C_4 (-0.022 \text{ cosec } E)$$

$$+ C_5 \left(\frac{X}{R}\right) + C_6 \left(\frac{Y}{R}\right) + C_7 \left(\frac{Z}{R}\right) \quad , \qquad (1)$$

Azimuth

$$\Delta A = D_0 + D_1\dot{A} + D_3\ddot{A} + D_5 \tan E + D_6 \sec E + D_7 \tan E \sin A + D_8 \tan E \cos A + D_9 \left(\frac{\sin A \cos A}{X}\right) + D_{10} \left(\frac{\sin A \cos A}{Y}\right) + D_{11}\dot{A} \sec E \quad , \tag{2}$$

Elevation

$$\Delta E = F_0 + F_1\dot{E} + F_3\ddot{E} + F_5(-\sin A) + F_6 \cos A + F_7 \left[\left(\frac{0.022}{R \sin E} - 10^{-6}\right) \operatorname{cotan} E\right] + F_9 \left(\frac{-X \tan E}{R^2}\right) + F_{10} \left(\frac{-Y \tan E}{R^2}\right) + F_{11} \left(\frac{\cos E}{R}\right) + F_{12}\,\dot{E} \cos E \quad . \tag{3}$$

Truncated versions of these models are presented wherein only the most significant variables are retained.

SUMMARY OF THE APOLLO-SATURN V RESULTS THROUGH THE AS-504 LAUNCH

Discussion

The Apollo-Saturn V AS-504 vehicle was launched at 11:00:00 (A.M.) Eastern Standard Time on March 3, 1969, from Kennedy Space Center, Launch Complex 39, Pad A. Tracking data from six C-band radars providing coverage on the launch phase and one providing coverage on the second burn phase were used in the TEMS reduction. Reference 3 contains information on the postflight reference trajectory used as the standard in the reduction.

An illustration of the vehicle launch phase ground track is shown in Figure 1. Location data, in terms of latitude, longitude, and height, for the launch site and the various tracking stations is given in Table 1.

The specific launch phase tracking data utilization is shown in Figure 2. Time spans of usable second burn data from the radar located at Antigua (91.18) are listed below:

(1) 17249.0 - 17406.0

(2) 17417.0 - 17668.0

All of these data were processed with the parameter weight matrix, coefficient approximation matrix, and a priori coefficient matrix equal to zero.

The general approach for obtaining truncated error models to describe the AS-504 range, azimuth, and elevation response variables is the same as the approach described in References 1 and 2. An underlying assumption in the approach is that survey terms, the rate bias term, and the azimuth and elevation velocity lag terms are not required in the error models. Furthermore, only the three most significant variables as determined in the stepwise regression are considered for the final TEMS error model. This approach results in entering the most significant variables into the error models.

Results

Tables 2 - 8 contain a summary of the truncated launch phase error model results obtained from the Apollo-Saturn 501-504 flight tests. A summary of the AS-504 second burn results for Radar 91.18 is presented in Table 9. The least squares residual errors presented in Tables 2 - 8 are averaged and summarized in Table 10. Several of the values in this table are slightly higher than the input accuracy estimates of 5 meters in range and 0.0060 degrees in azimuth and elevation. It should be pointed out that on the AS-504 flight, Radar 0.18 was committed to the best available skin track. This is reflected in the σ_{VR} and σ_{VA} values for the AS-504 data in Table 2.

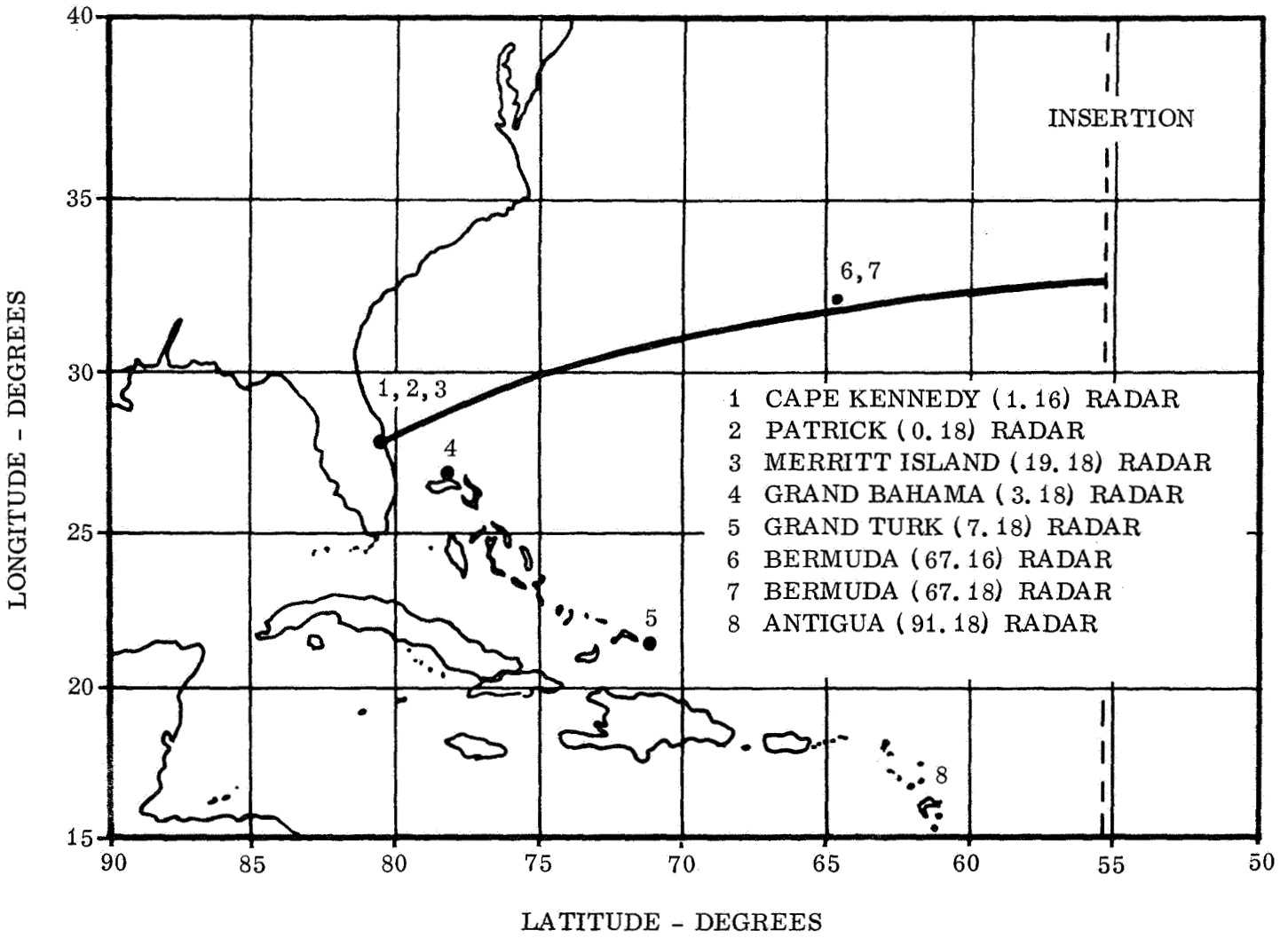

Figure 1. AS-504 launch phase ground track.

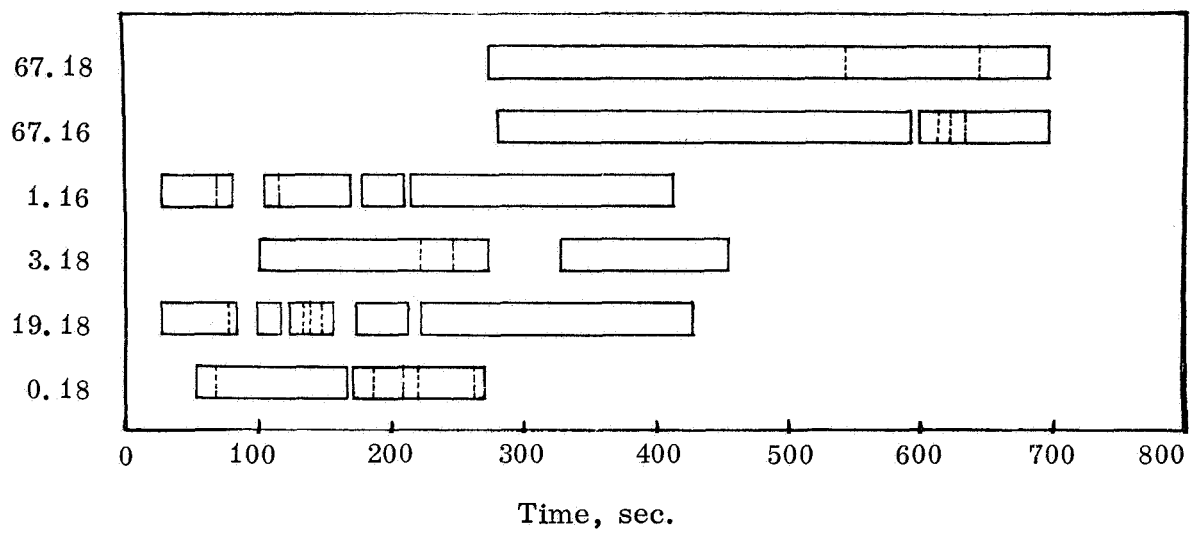

Figure 2. TEMS AS-504 tracking data utilization.

The coefficient standard deviation data in Tables 2 - 8 are summarized in Table 11. It is shown in this table that the value of σ_{D_3} for the Bermuda Radars is significantly less than the values obtained for the Cape and Grand Bahama Radars. It is also shown that the values of σ_{F_3} for the Cape, Bermuda, and Grand Bahama Radars differ by orders of magnitude. The other coefficient standard deviations do not vary significantly from radar to radar. This observation was noted in the previous TEMS report [1].

The total number of terms required in the truncated error models for the AS 501-504 launch phase data are presented in Table 12. It is interesting to note that 15 of the 24 error models required eight terms.

Figure 3 shows the frequency of occurrence of the individual coefficients in the truncated error models. As noted in Reference 1, the servo lag errors in the azimuth and elevation measurements have a high frequency of occurrence as well as the scale factor and timing delay errors in range. All of these error terms were required in the AS-504 models with the exception of the C_1R term in the 3. 18 model and the F_3E term in the 67. 18 model.

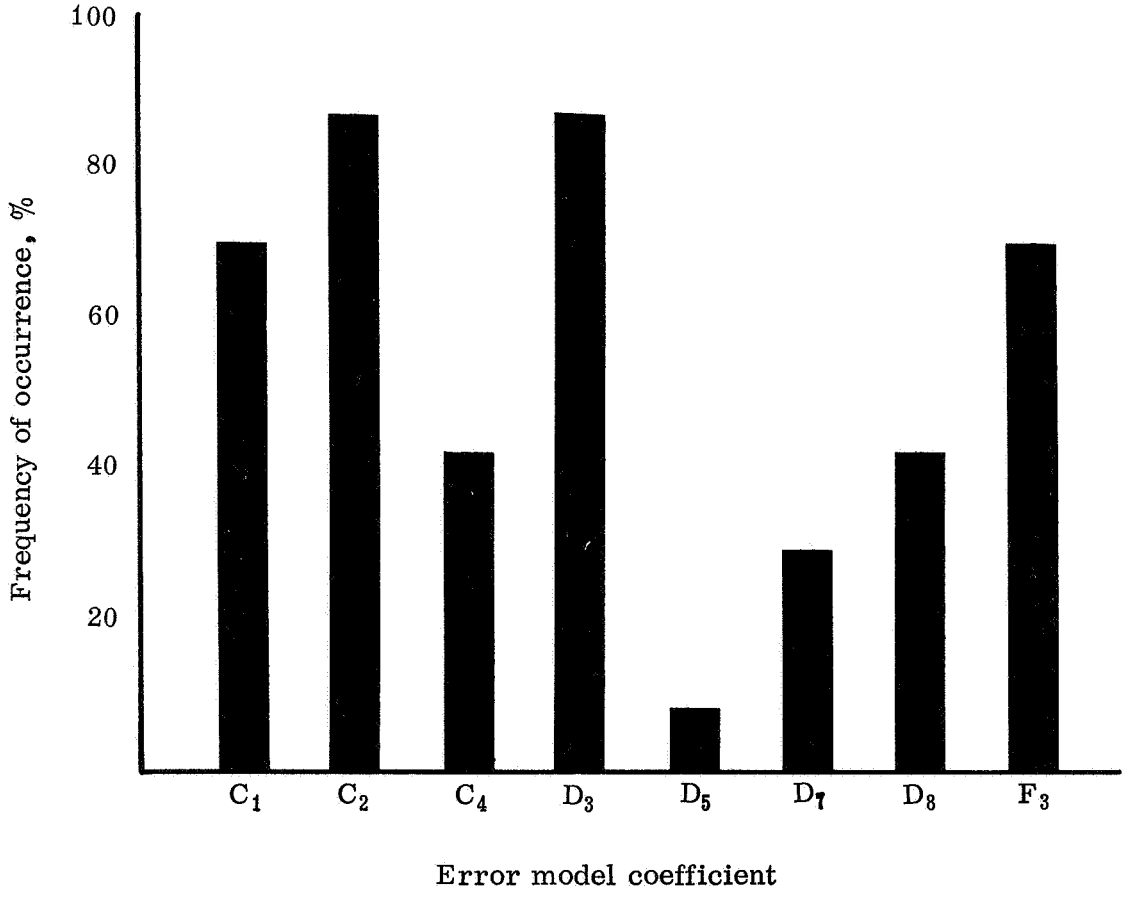

Figure 3. Frequency of occurrence of error model coefficients on AS 501-504 launch phase.

CONCLUSIONS

Results from the evaluation of C-Band radar tracking system errors on the Apollo-Saturn V 501-504 flight tests are presented. These results were obtained by using the TEMS Multiple Regression Analysis Method in conjunction with a stepwise regression procedure. It is shown that the coefficient standard deviation of the azimuth servo lag error model term for the Bermuda Radars is significantly less than the values obtained for the Cape and Grand Bahama Radars. It is also shown that the coefficient standard deviations of the elevation servo lag error terms for the Cape, Bermuda, and Grand Bahama Radars differ by orders of magnitude. As found in the previous TEMS reports, the servo lag errors in azimuth and elevation, and the scale factor and timing delay errors in range, have a high frequency of occurrence in the truncated error models.

TABLE 1. LOCATION OF LAUNCH SITE AND C-BAND TRACKING RADARS USED IN TEMS AS-504 REDUCTION

Site	Latitude, Degrees	Longitude, Degrees	Height,[a] Meters
Launch Complex 39, Pad A	28.608422	80.604133	115.98[b]
Patrick Radar (0.18)	28.226553	80.599293	20.42
Merritt Island Radar (19.18)	28.424862	80.664404	16.80
Grand Bahama Radar (3.18)	26.636350	78.267708	16.68
67.16 (FPS-16)	32.348103	64.653801	17.81
67.18 (FPQ-6)	32.347964	64.653742	19.03
Cape Kennedy (1.16)	28.481766	80.576515	18.78
Antigua Radar (91.18)	17.144040	61.792871	57.37

a. Elevation above the Fischer Ellipsoid

b. Elevation of the C-band radar antenna above the Fischer Ellipsoid

TABLE 2. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 0.18 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	-19.92	-4.76	32.39	16.85
σ	0.84	0.57	1.08	1.70
$C_1 \times 10^{-4}$	—	-0.520	—	-4.50
$\sigma \times 10^{-4}$	—	0.023	—	0.17
$C_2 \times 10^{-3}$	9.10	5.70	-1.70	75.52
$\sigma \times 10^{-3}$	0.25	0.44	0.34	1.86
C_4	23.71	—	186.85	—
σ	5.21	—	8.09	—
$D_0 \times 10^{-3}$	8.70	4.40	-6.00	-23.77
$\sigma \times 10^{-3}$	0.54	0.30	0.52	1.70
D_3	0.6915	0.0341	0.6545	4.7046
σ	0.0740	0.0480	0.1095	0.1834
D_5	—	—	—	—
σ	—	—	—	—
D_7	-0.0202	—	—	0.0938
σ	0.0015	—	—	0.0050
$D_8 \times 10^{-3}$	—	—	20.20	—
$\sigma \times 10^{-3}$	—	—	1.70	—
$F_0 \times 10^{-3}$	19.40	17.00	30.60	-67.78
$\sigma \times 10^{-3}$	0.93	0.30	1.50	3.53
F_3	0.1791	-0.4858	-1.6755	1.8453
σ	0.1000	0.0710	0.1180	0.2246
No. Data Pts.	335	311	297	191
σ_{VR}, Meters	3.96	4.64	6.45	15.02
σ_{VA}, Degrees	0.0082	0.0041	0.0074	0.0115
σ_{VE}, Degrees	0.0072	0.0055	0.0062	0.0066

TABLE 3. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 19.18 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	-18.11	-13.94	-16.74	10.56
σ	0.72	0.76	0.65	0.76
$C_1 \times 10^{-4}$	—	-0.250	-1.200	-1.790
$\sigma \times 10^{-4}$	—	0.017	0.033	0.028
$C_2 \times 10^{-3}$	5.50	—	20.00	40.61
$\sigma \times 10^{-3}$	0.33	—	0.51	0.62
C_4	-36.03	-37.69	—	—
σ	3.75	13.97	—	—
$D_0 \times 10^{-3}$	0.70	-9.3	2.00	-2.16
$\sigma \times 10^{-3}$	1.00	1.1	0.30	0.44
D_3	—	-0.1339	—	2.4796
σ	—	0.0580	—	0.0819
D_5	0.0697	0.0530	—	—
σ	0.0024	0.0023	—	—
D_7	-0.0761	-0.0492	—	—
σ	0.0016	0.0013	—	—
$D_8 \times 10^{-3}$	—	—	—	67.38
$\sigma \times 10^{-3}$	—	—	—	1.62
$F_0 \times 10^{-3}$	33.00	52.30	19.00	69.60
$\sigma \times 10^{-3}$	1.00	1.00	0.30	1.39
F_3	-0.439	—	—	-1.9820
σ	0.050	—	—	0.0815
No. Data Pts.	219	247	205	333
σ_{VR}, Meters	5.23	3.54	2.20	4.62
σ_{VA}, Degrees	0.0046	0.0036	0.0030	0.0072
σ_{VE}, Degrees	0.0062	0.0050	0.0072	0.0073

TABLE 4. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 3.18 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	5.21	5.43	-9.44	49.95
σ	0.36	0.63	0.55	0.71
$C_1 \times 10^{-4}$	——	——	0.15	——
$\sigma \times 10^{-4}$	——	——	0.01	——
$C_2 \times 10^{-3}$	6.60	-10.20	——	4.89
$\sigma \times 10^{-3}$	0.11	0.17	——	0.17
C_4	93.25	258.24	8.64	194.52
σ	2.27	4.72	3.03	4.00
$D_0 \times 10^{-3}$	5.40	3.20	-12.90	-5.43
$\sigma \times 10^{-3}$	0.23	0.34	0.28	0.40
D_3	0.5517	1.0550	1.1270	1.2033
σ	0.0860	0.1240	0.0970	0.1282
D_5	——	——	——	——
σ	——	——	——	——
D_7	——	——	——	——
σ	——	——	——	——
$D_8 \times 10^{-3}$	——	——	15.70	24.16
$\sigma \times 10^{-3}$	——	——	0.50	0.64
$F_0 \times 10^{-3}$	-0.84	1.00	15.00	1.73
$\sigma \times 10^{-3}$	0.24	0.33	0.30	0.40
F_3	2.1000	——	1.0520	0.1384
σ	0.1730	——	0.1880	0.2490
No. Data Pts.	395	354	361	287
σ_{VR}, Meters	4.02	5.39	4.87	7.99
σ_{VA}, Degrees	0.0027	0.0064	0.0042	0.0032
σ_{VE}, Degrees	0.0055	0.0058	0.0049	0.0040

TABLE 5. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 1.16 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	-36.91	-23.65	-7.14	-6.29
σ	1.03	1.54	0.93	1.09
$C_1 \times 10^{-4}$	-0.590	-0.240	-2.10	-2.04
$\sigma \times 10^{-4}$	0.067	0.037	0.01	0.04
$C_2 \times 10^{-3}$	17.10	——	27.90	45.65
$\sigma \times 10^{-3}$	0.89	——	0.88	0.86
C_4	——	177.78	——	——
σ	——	27.80	——	——
$D_0 \times 10^{-3}$	17.10	2.40	3.60	-8.10
$\sigma \times 10^{-3}$	1.14	0.62	0.72	0.60
D_3	0.3386	0.1526	0.5433	1.0073
σ	0.0730	0.0550	0.0492	0.0553
D_5	——	——	——	——
σ	——	——	——	——
D_7	-0.0177	——	——	——
σ	0.0025	——	——	——
$D_8 \times 10^{-3}$	——	——	——	51.49
$\sigma \times 10^{-3}$	——	——	——	1.50
$F_0 \times 10^{-3}$	4.20	21.80	24.70	67.66
$\sigma \times 10^{-3}$	1.57	0.62	0.65	1.26
F_3	——	-0.5808	-0.6287	-1.7208
σ	——	0.0740	0.0580	0.0813
No. Data Pts.	225	209	187	341
σ_{VR}, Meters	4.31	4.70	7.75	6.30
σ_{VA}, Degrees	0.0121	0.0100	0.0072	0.0084
σ_{VE}, Degrees	0.0106	0.0105	0.0099	0.0126

TABLE 6. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 7.18 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	-12.28	NA	NA	NA
σ	0.95			
$C_1 \times 10^{-4}$	——			
$\sigma \times 10^{-4}$	——			
$C_2 \times 10^{-3}$	2.40			
$\sigma \times 10^{-3}$	0.30			
C_4	36.20			
σ	1.97			
$D_0 \times 10^{-3}$	-17.60			
$\sigma \times 10^{-3}$	0.64			
D_3	-2.840			
σ	0.971			
D_5	——			
σ	——			
D_7	——			
σ	——			
$D_8 \times 10^{-3}$	——			
$\sigma \times 10^{-3}$	——			
$F_0 \times 10^{-3}$	-8.50			
$\sigma \times 10^{-3}$	0.61			
F_3	——			
σ	——			
No. Data Pts.	297			
σ_{VR}, Meters	6.09			
σ_{VA}, Degrees	0.0038			
σ_{VE}, Degrees	0.0165			

TABLE 7. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 67.16 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	58.47	NA	-3.78	3.29
σ	1.15		1.00	0.55
$C_1 \times 10^{-4}$	-1.140		-0.420	-0.3520
$\sigma \times 10^{-4}$	0.021		0.015	0.0075
$C_2 \times 10^{-3}$	-2.20		0.028	-1.127
$\sigma \times 10^{-3}$	0.09		0.085	0.048
C_4	——		——	——
σ	——		——	——
$D_0 \times 10^{-3}$	0.34		-9.20	-5.13
$\sigma \times 10^{-3}$	0.56		0.50	0.28
D_3	0.1632		-0.0434	0.0141
σ	0.0050		0.0053	0.0028
D_5	——		——	——
σ	——		——	——
D_7	——		——	——
σ	——		——	——
$D_8 \times 10^{-3}$	8.30		9.40	6.56
$\sigma \times 10^{-3}$	0.48		0.47	0.26
$F_0 \times 10^{-3}$	7.30		16.60	3.81
$\sigma \times 10^{-3}$	0.54		0.50	0.28
F_3	0.2380		0.1329	0.1305
σ	0.0140		0.0181	0.0083
No. Data Pts.	289		338	388
σ_{VR}, Meters	9.75		5.15	1.81
σ_{VA}, Degrees	0.0097		0.0108	0.0058
σ_{VE}, Degrees	0.0051		0.0101	0.0071

TABLE 8. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 67.18 LAUNCH PHASE DATA

Coefficient Value and Standard Deviation	Flight Test No.			
	501	502	503	504
C_0	84.34	216.63	26.49	14.79
σ	0.84	1.99	0.67	0.57
$C_1 \times 10^{-4}$	-0.970	-2.600	-0.380	-0.3660
$\sigma \times 10^{-4}$	0.015	0.027	0.010	0.0077
$C_2 \times 10^{-3}$	-4.90	-27.20	0.10	-1.02
$\sigma \times 10^{-3}$	0.10	0.18	0.02	0.49
C_4	—	—	—	—
σ	—	—	—	—
$D_0 \times 10^{-3}$	5.60	-8.10	-16.20	-7.55
$\sigma \times 10^{-3}$	0.46	1.10	0.34	0.36
D_3	0.0192	—	0.0362	0.0914
σ	0.0040	—	0.0053	0.0041
D_5	—	—	—	-0.0184
σ	—	—	—	0.0005
D_7	—	—	-0.0278	-0.0135
σ	—	—	0.0008	0.0007
$D_8 \times 10^{-3}$	6.70	4.60	—	—
$\sigma \times 10^{-3}$	0.43	0.93	—	—
$F_0 \times 10^{-3}$	2.10	22.8	1.30	-1.03
$\sigma \times 10^{-3}$	0.48	1.0	0.38	0.37
F_3	-0.0027	—	0.0247	—
σ	0.0120	—	0.0118	—
No. Data Pts.	297	431	407	416
σ_{VR}, Meters	9.16	29.21	5.40	2.21
σ_{VA}, Degrees	0.0045	0.0063	0.0062	0.0073
σ_{VE}, Degrees	0.0057	0.0110	0.0079	0.0064

TABLE 9. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 91.18 AS-504 SECOND BURN DATA

Coefficient	Value	Standard Deviation
C_0	44.17	0.73
C_1	-0.196×10^{-4}	0.0072×10^{-4}
C_2	-0.00786	0.52×10^{-4}
C_4	———	———
D_0	0.0015	0.40×10^{-3}
D_3	1.0558	0.0077
D_5	———	———
D_7	-0.0023	0.67×10^{-3}
D_8	———	———
F_0	-0.0033	0.41×10^{-3}
F_3	0.2760	0.0298

No. Data Pts.	406
σ_{VR}, Meters	3.72
σ_{VA}, Degrees	0.0090
σ_{VE}, Degrees	0.0095

TABLE 10. RESIDUAL ERROR SUMMARY FOR TRACKING RADARS ON AS 501-504 LAUNCH PHASE

Radar ID	σ_{VR}, Meters	σ_{VA}, Degrees	σ_{VE}, Degrees
0.18	7.51	0.0078	0.0064
3.18	5.57	0.0041	0.0050
19.18	3.89	0.0046	0.0064
1.16	5.61	0.0094	0.0109
7.18[a]	6.09	0.0038	0.0165
67.18	11.49	0.0060	0.0077
67.16	5.57	0.0088	0.0074

a. Data from AS-501 Flight

TABLE 11. COEFFICIENT STANDARD DEVIATION SUMMARY FOR TRACKING RADARS ON AS 501-504 LAUNCH PHASE

Coefficient Standard Deviation	All Radars	Cape Radars 19.18 0.18 1.16	Bermuda Radars 67.16 67.18	Grand Bahama Radar 3.18	Grand Turk Radar 7.18
σ_{C_0}	0.90	0.97	0.97	0.56	0.95
$\sigma_{C_1} \times 10^{-5}$	0.37	0.57	0.15	0.10	—
$\sigma_{C_2} \times 10^{-3}$	0.42	0.70	0.15	0.15	0.30
σ_{C_4}	7.48	11.76	—	3.50	1.97
$\sigma_{D_0} \times 10^{-3}$	0.60	0.75	0.51	0.31	0.67
σ_{D_3}	a	0.079	0.0044	0.109	0.971
σ_{D_5}	0.0017	0.0023	0.0005	—	—
σ_{D_7}	0.0005	0.0024	0.0007	—	—
$\sigma_{D_8} \times 10^{-3}$	0.0009	0.0016	0.0007	0.0006	—
$\sigma_{F_0} \times 10^{-3}$	0.82	1.17	0.50	0.31	0.61
σ_{F_3}	a	0.095	0.013	0.199	—

a. Not combined

TABLE 12. TOTAL NUMBER OF TERMS IN TRUNCATED ERROR MODELS FOR AS 501-504 LAUNCH PHASE

Radar ID	Flight Test No.			
	501	502	503	504
0.18	8	7	8	8
3.18	7	6	8	8
19.18	8	8	5	8
1.16	7	7	7	8
7.18	6	NA	NA	NA
67.18	8	6	8	8
67.16	8	NA	8	8

APPENDIX

RESULTS FROM THE APOLLO-SATURN 504 VEHICLE FLIGHT TEST

This appendix presents a summary of the results from the Apollo-Saturn 504 Vehicle Flight Test launched on March 3, 1969. The Stepwise Regression Analysis results for the launch phase data are presented in Table A1. Coefficient correlations and the stepwise results for Radar 91.18 second burn data are presented in Tables A2 and A3, respectively. The launch phase coefficient correlations are presented in Table A4.

In the figures (A-1 through A-14), the tracking errors for the various radars are represented by dots. The description of these errors as obtained from the TEMS least squares adjustment program is represented by the solid computed curves.

The least squares residuals for the truncated error models presented in this appendix can be thought of as being composed of random errors and unmodeled systematic errors. A high random error content in the data may prevent a systematic error of comparable magnitude from being determined. The latter errors are those that can be attributed to uncertainties in the standard used in establishing the tracking errors, unknown systematic errors not absorbed by those that are modeled, or to geometry limitations. The presence of a significant unmodeled systematic error may prevent an adequate description of the data from being obtained.

TABLE A1. STEPWISE REGRESSION ANALYSIS RESULTS FOR AS-504 LAUNCH PHASE DATA

Radar Equation	Variables in Regression	σ_y	F Level
0.18			
ΔR	$C_0\ C_6\ C_4$	12.63	39.4
ΔA	$D_0\ D_7\ D_8$	0.0082	-0.4
ΔE	$F_0\ D_8\ F_3$	0.0057	23.2
19.18			
ΔR	$C_0\ C_6\ C_7\ C_8\ C_2$	2.03	102.1
ΔA	$D_0\ C_2\ C_5\ D_3$	0.0051	166.5
ΔE	$F_0\ D_7\ C_7\ C_6\ F_3\ D_8\ C_2$	0.0033	-1.1
3.18			
ΔR	$C_0\ C_4\ C_5\ C_6\ C_7$	1.31	52.8
ΔA	$D_0\ C_2\ C_6\ D_6\ D_8\ D_3$	0.0021	3.7
ΔE	$F_0\ D_8$	0.0040	3564.6
1.16			
ΔR	$C_0\ C_7\ C_5\ C_8\ C_2$	3.47	3.9
ΔA	$D_0\ C_2\ C_5\ D_3\ D_8$	0.0058	13.0
ΔE	$F_0\ D_7\ C_2\ D_8\ C_5\ C_7\ C_6$	0.0075	20.9
67.16			
ΔR	$C_0\ C_1\ C_8\ C_2\ C_4$	1.40	-1.2
ΔA	$D_0\ D_3\ D_6\ D_5\ C_2$	0.0054	34.2
ΔE	$F_0\ D_8\ F_3\ C_4\ D_7\ C_7$	0.0066	3.8
67.18			
ΔR	$C_0\ C_1\ C_6\ C_2\ C_7\ C_8\ C_4$	1.24	15.1
ΔA	$D_0\ C_2\ D_3\ D_7\ D_5$	0.0069	21.4
ΔE	$F_0\ D_7\ F_3\ C_4\ C_6$	0.0058	10.4

TABLE A2. COEFFICIENT CORRELATIONS FOR THE TRUNCATED 91.18 AS-504 SECOND BURN ERROR MODELS

	C_0	C_1	C_2	D_0	D_3	D_7	F_0	F_3
C_0	1.0	-0.89	0.23	-0.01	0.0	-0.01	0.0	0.0
C_1		1.0	-0.38	0.01	0.0	0.02	0.0	0.0
C_2			1.0	-0.03	-0.01	-0.05	0.01	-0.01
D_0				1.0	-0.06	-0.17	0.01	0.0
D_3					1.0	0.54	-0.02	-0.01
D_7						1.0	-0.04	-0.02
F_0							1.0	-0.26
F_3								1.0

TABLE A3. STEPWISE REGRESSION ANALYSIS RESULTS FOR 91.18 AS-504 SECOND BURN DATA

Equation	Variables in Regression	σ_y	F Level
ΔR	C_0 C_7 C_5 C_8 C_4 C_1	1.96	8.7
ΔA	D_0 D_3 D_7 D_5 D_6	0.0083	5.7
ΔE	F_0 C_6 F_3 C_5 C_4 C_7	0.0087	4.7

TABLE A4. COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-504 LAUNCH PHASE ERROR MODELS

	C_0	C_1	C_2	D_0	D_3	D_7	F_0	F_3
C_0	1.0	0.01	-0.41	0.05	0.07	0.12	-0.10	0.02
C_1		1.0	-0.88	0.10	0.15	0.26	-0.22	0.04
C_2			1.0	-0.12	-0.17	-0.29	0.25	-0.04
D_0				1.0	-0.37	-0.70	0.67	-0.15
D_3					1.0	0.53	-0.50	0.11
D_7						1.0	-0.94	0.20
F_0							1.0	-0.08
F_3								1.0

Radar 0.18

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1.0	0.48	-0.73	-0.05	0.01	0.27	0.26	-0.03
C_1		1.0	-0.93	-0.06	0.01	0.35	0.34	-0.04
C_2			1.0	0.07	-0.02	-0.37	-0.36	0.04
D_0				1.0	-0.08	-0.52	-0.50	0.14
D_3					1.0	0.02	0.02	0.0
D_8						1.0	0.96	-0.25
F_0							1.0	-0.24
F_3								1.0

Radar 19.18

TABLE A4. (Continued)

	C_0	C_2	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1.0	-0.50	0.79	0.05	0.0	0.01	0.03	0.0
C_2		1.0	-0.09	-0.10	-0.01	-0.05	-0.03	0.0
C_4			1.0	0.01	0.0	-0.01	0.03	0.0
D_0				1.0	-0.20	-0.30	-0.08	0.01
D_3					1.0	0.07	0.02	0.0
D_8						1.0	0.27	-0.04
F_0							1.0	0.25
F_3								1.0

Radar 3.18

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1.0	0.49	-0.76	-0.02	0.03	0.38	0.34	-0.04
C_1		1.0	-0.91	-0.03	0.03	0.45	0.41	-0.05
C_2			1.0	0.03	-0.03	-0.49	-0.45	0.06
D_0				1.0	-0.02	-0.42	-0.38	0.08
D_3					1.0	0.0	0.0	0.0
D_8						1.0	0.91	-0.18
F_0							1.0	-0.18
F_3								1.0

Radar 1.16

TABLE A4. (Concluded)

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1.0	-0.91	0.03	0.0	0.0	0.0	0.0	0.0
C_1		1.0	0.02	0.0	0.0	0.0	0.0	0.0
C_2			1.0	0.04	0.01	-0.15	0.03	0.0
D_0				1.0	-0.02	0.20	-0.05	-0.01
D_3					1.0	-0.11	0.03	0.01
D_8						1.0	-0.26	-0.06
F_0							1.0	0.04
F_3								1.0

Radar 67.16

	C_0	C_1	C_2	D_0	D_3	D_5	D_7	F_0
C_0	1.0	-0.91	-0.05	0.0	0.0	-0.01	0.0	0.0
C_1		1.0	0.09	0.0	0.0	0.01	0.0	0.0
C_2			1.0	-0.04	-0.02	0.15	0.03	0.01
D_0				1.0	-0.13	-0.61	0.14	0.06
D_3					1.0	0.21	-0.69	-0.29
D_5						1.0	-0.22	-0.09
D_7							1.0	0.42
F_0								1.0

Radar 67.18

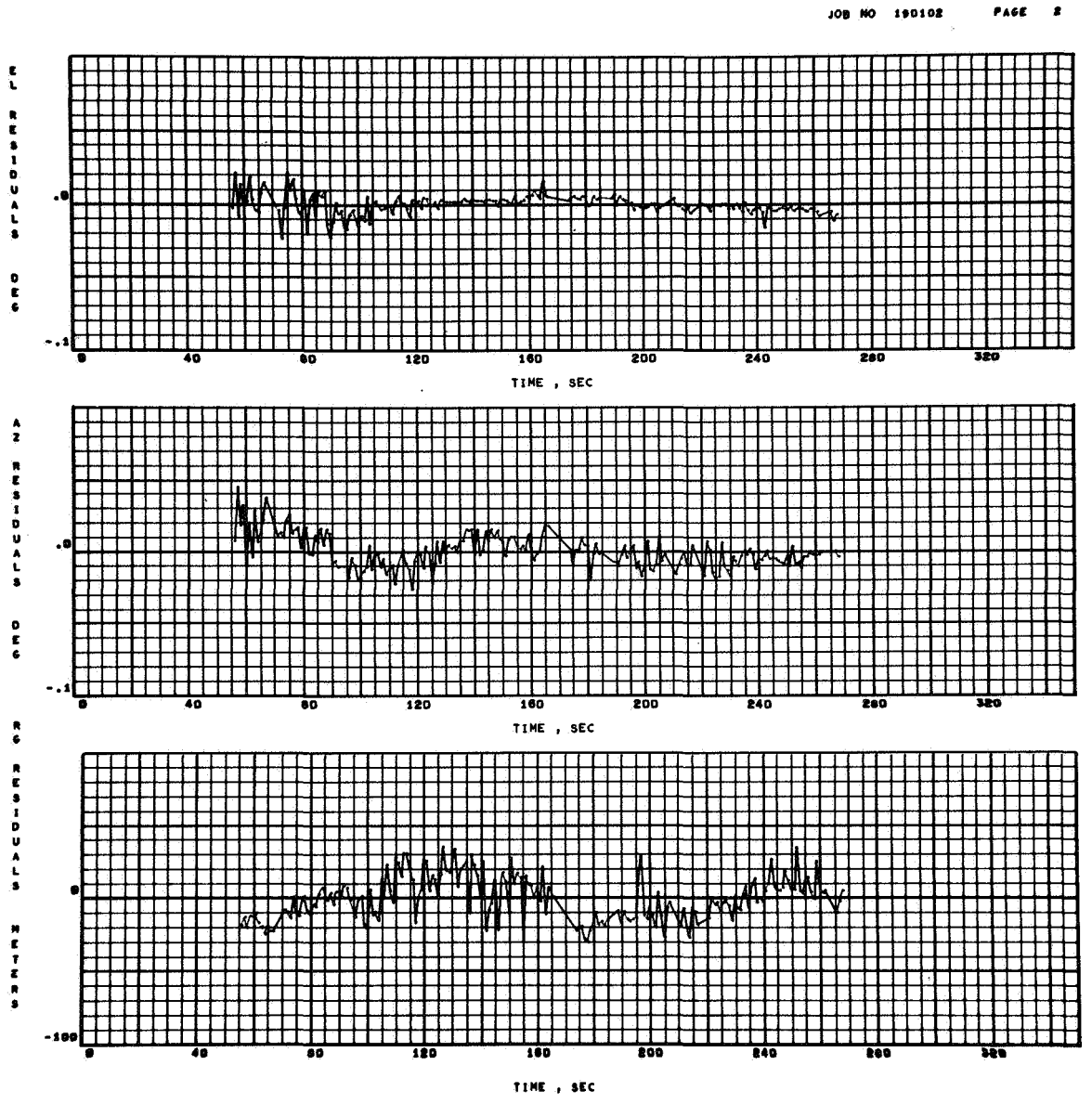

Figure A-1. Radar 0.18 residuals on AS-504 launch phase data.

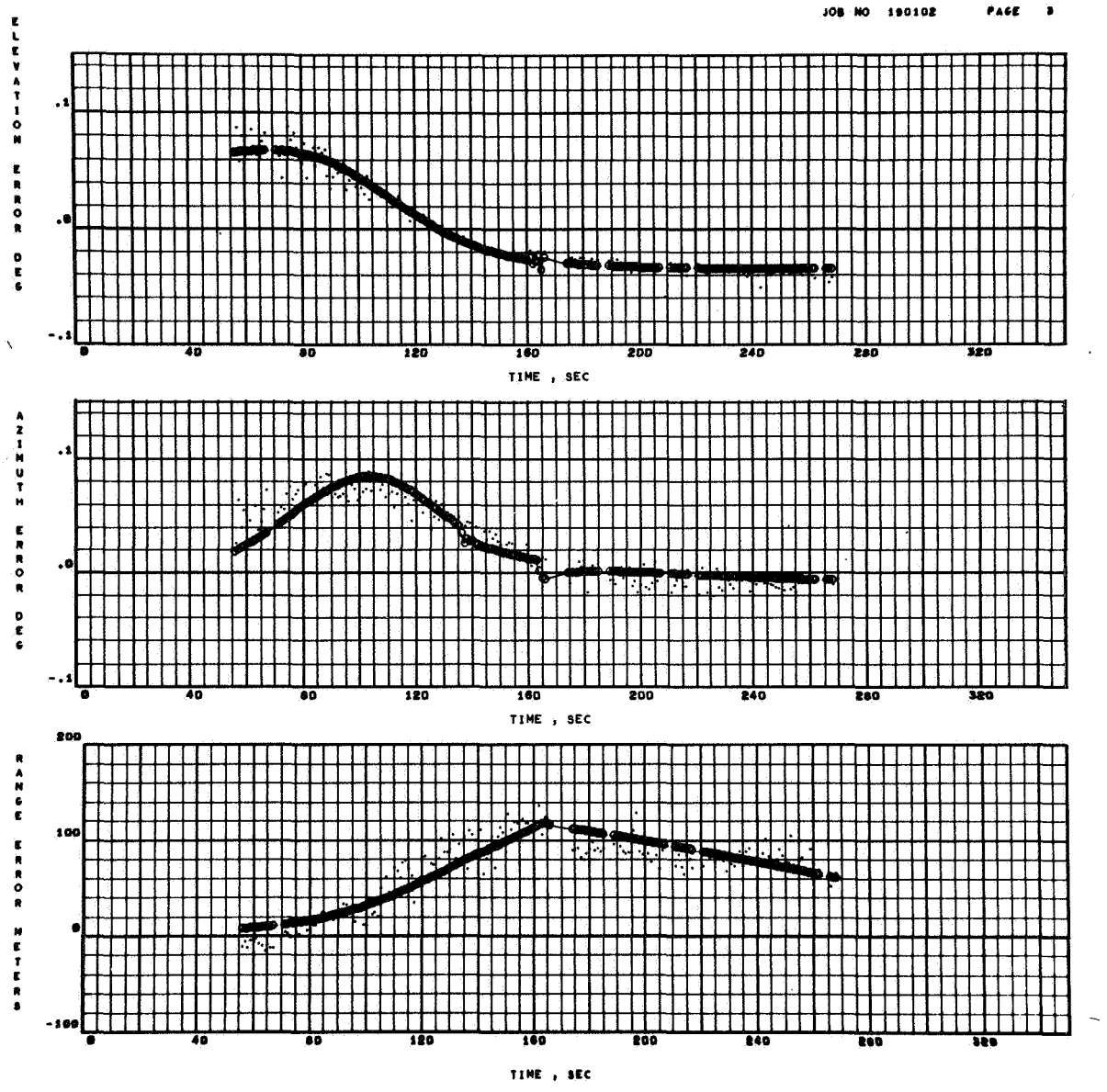

Figure A-2. Radar 0.18 range, azimuth, and elevation errors on AS-504 launch phase data.

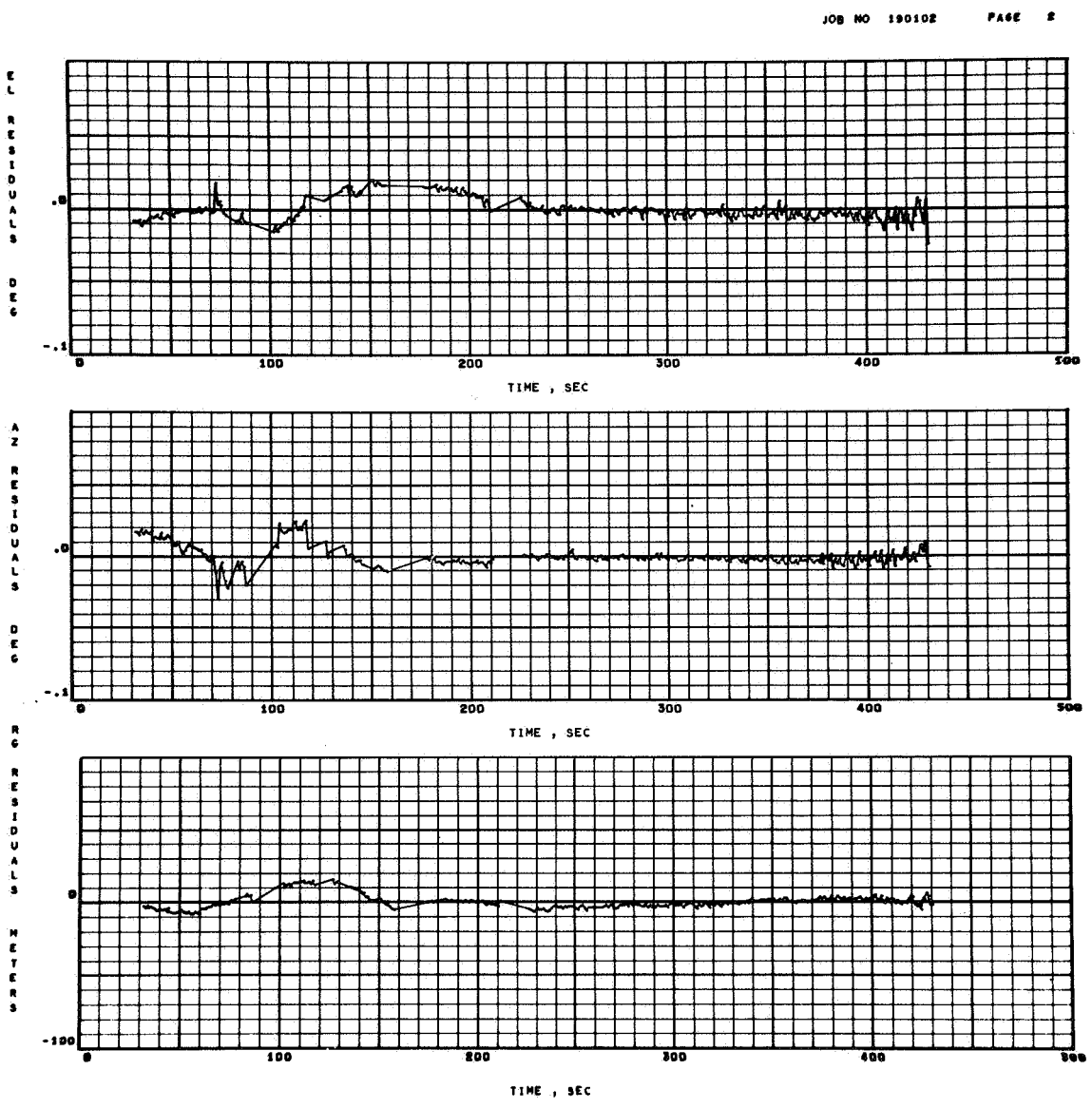

Figure A-3. Radar 19.18 residuals on AS-504 launch phase data.

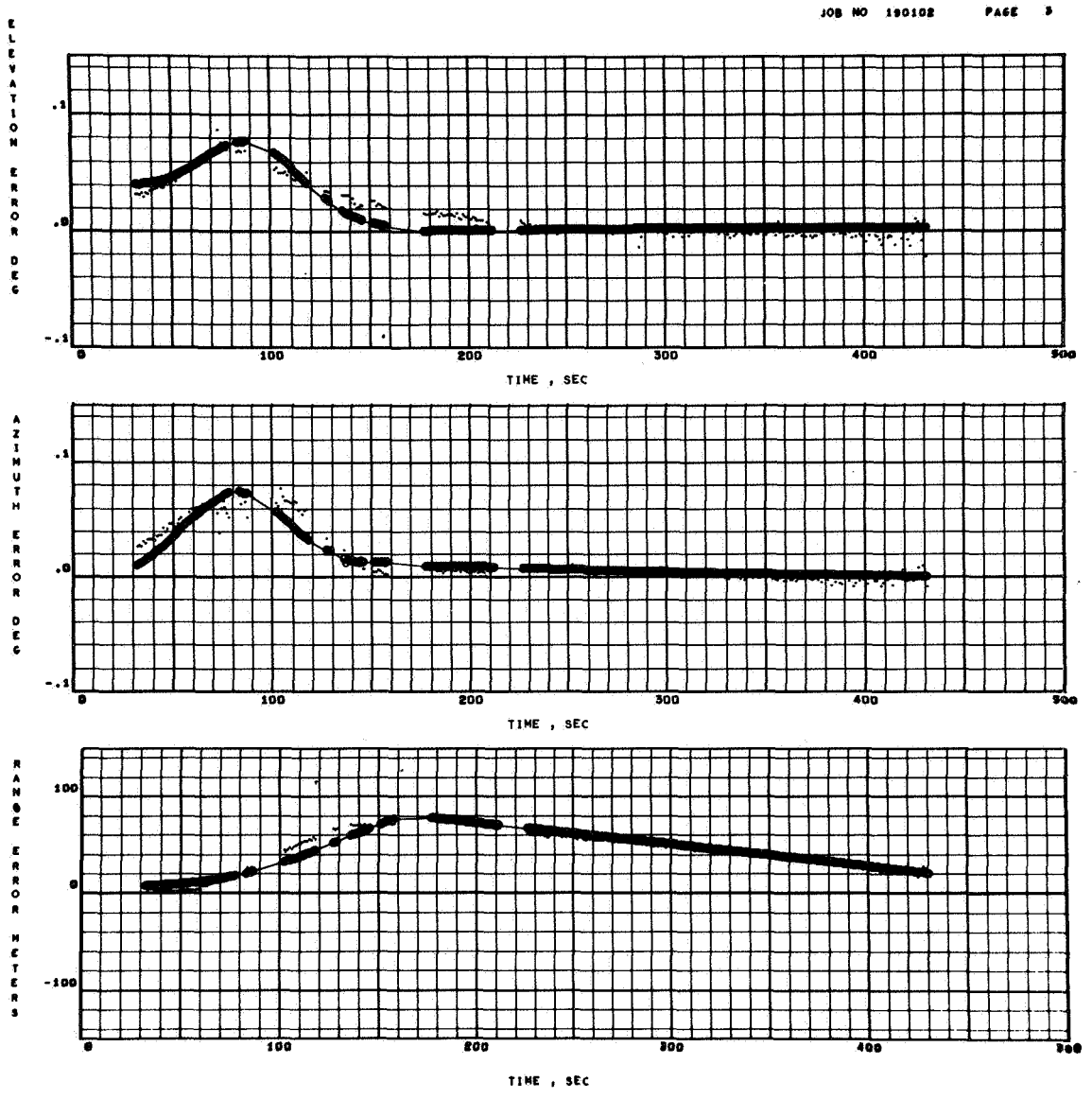

Figure A-4. Radar 19.18 range, azimuth, and elevation errors on AS-504 launch phase data.

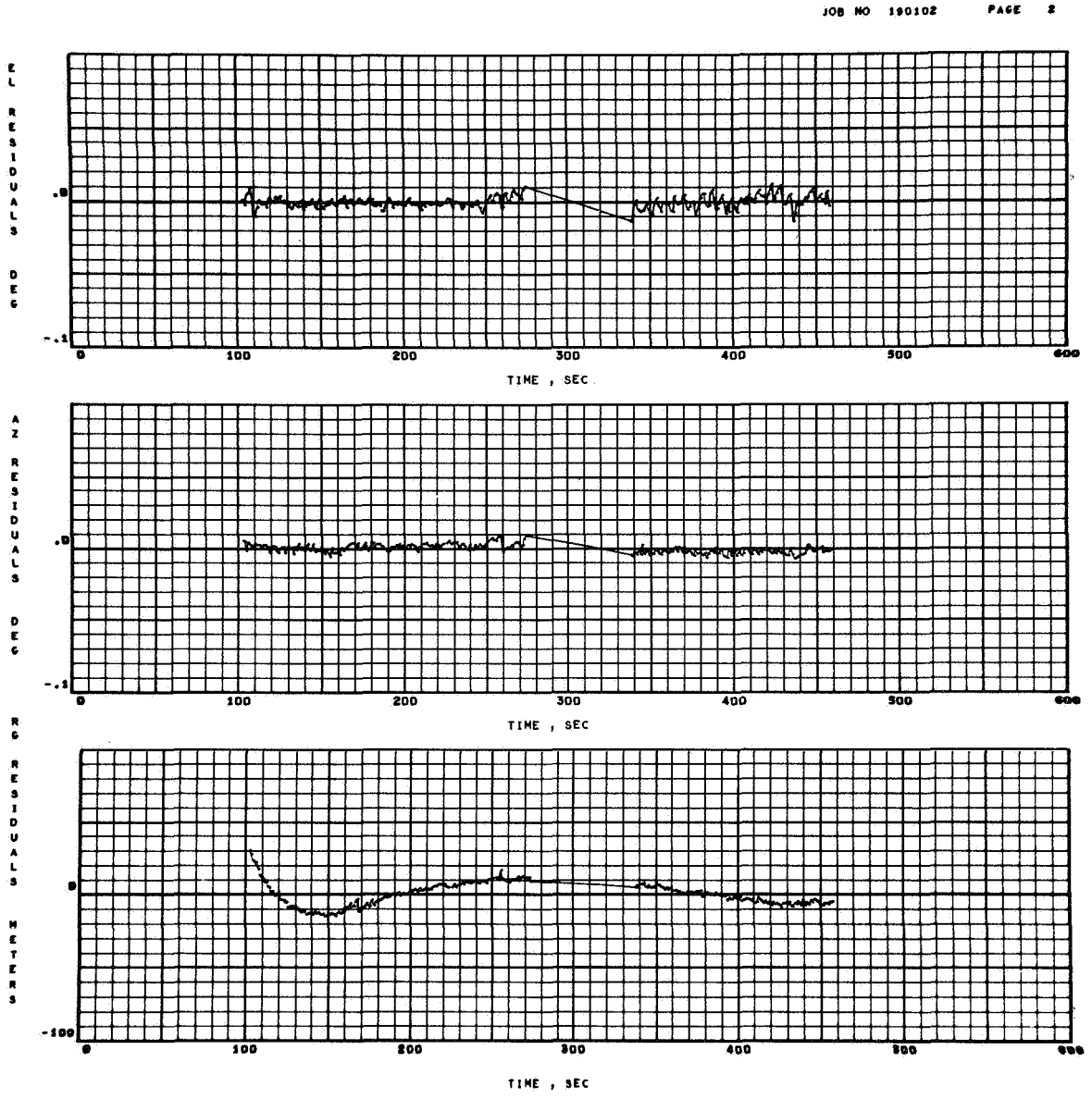

Figure A-5. Radar 3.18 residuals on AS-504 launch phase data.

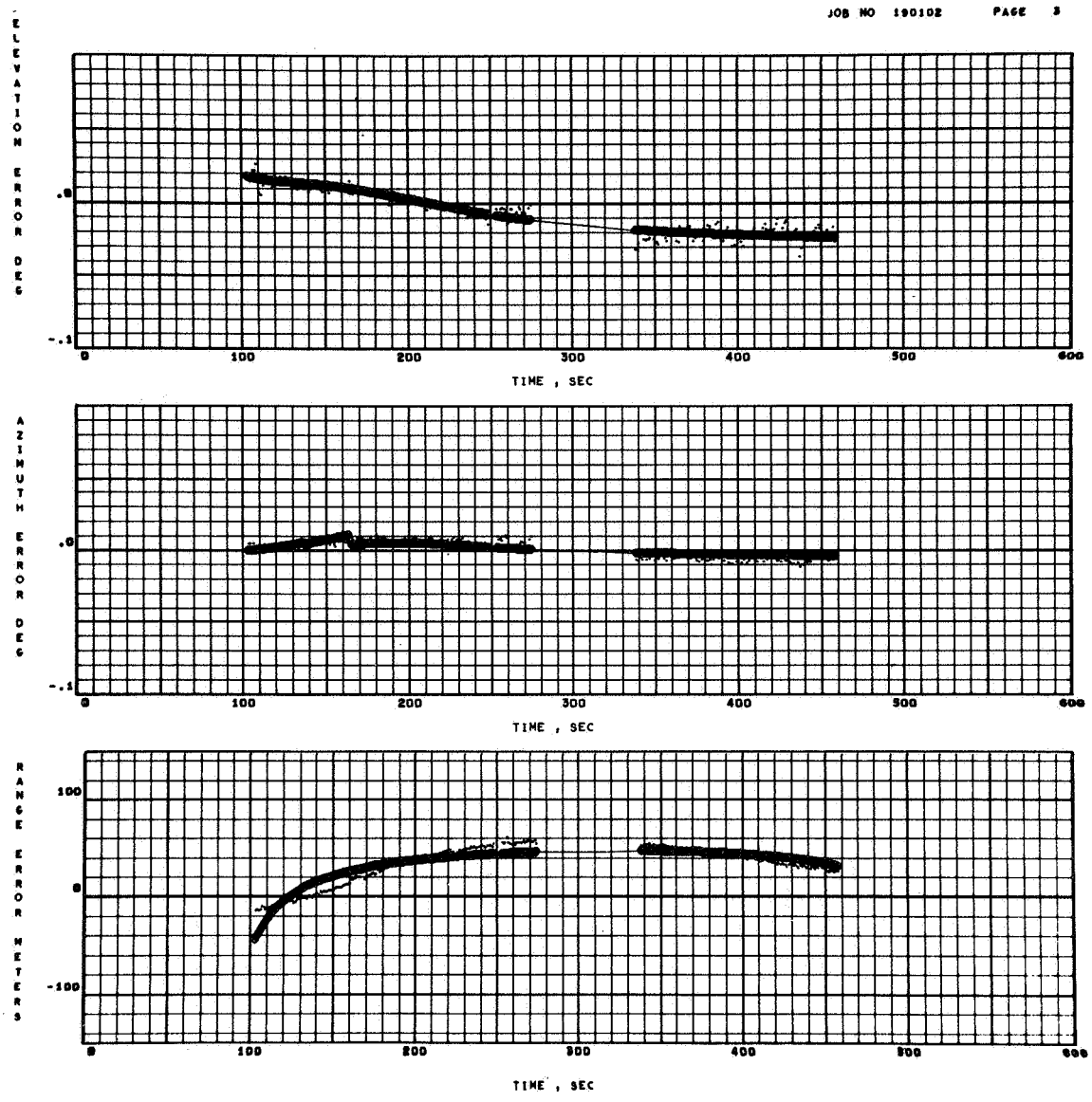

Figure A-6. Radar 3.18 range, azimuth, and elevation errors on AS-504 launch phase data.

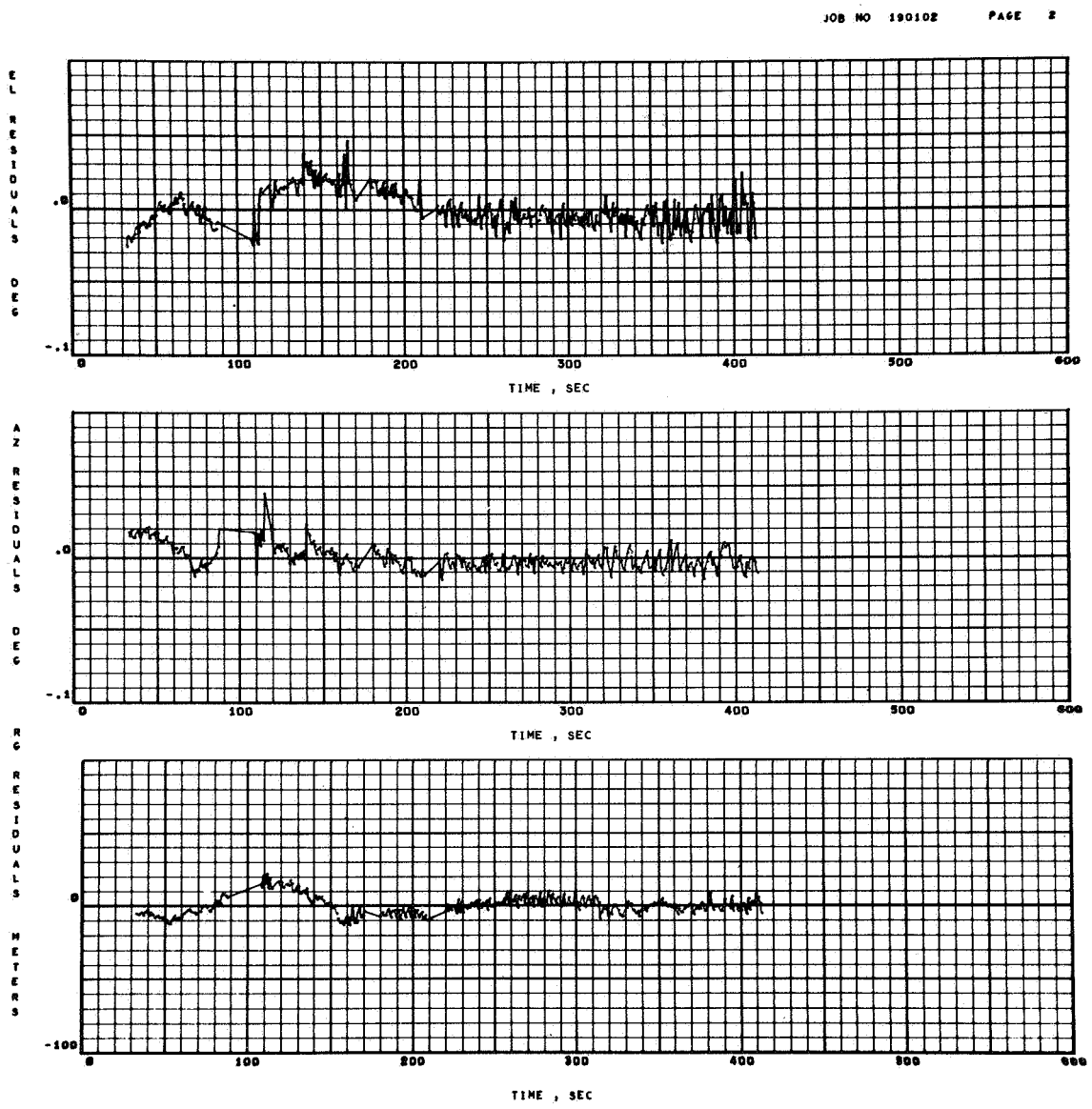

Figure A-7. Radar 1.16 residuals on AS-504 launch phase data.

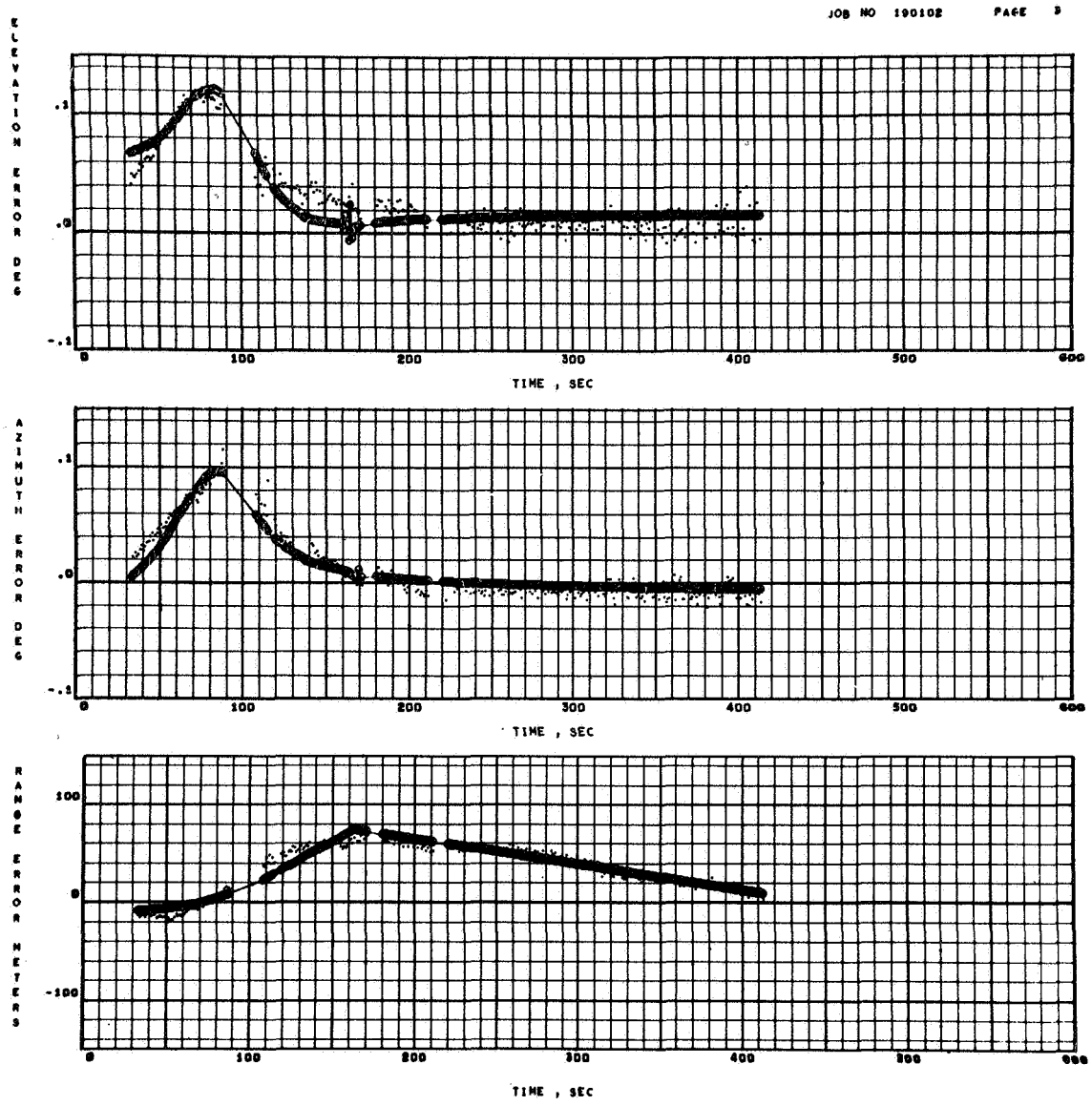

Figure A-8. Radar 1.16 range, azimuth, and elevation errors on AS-504 launch phase data.

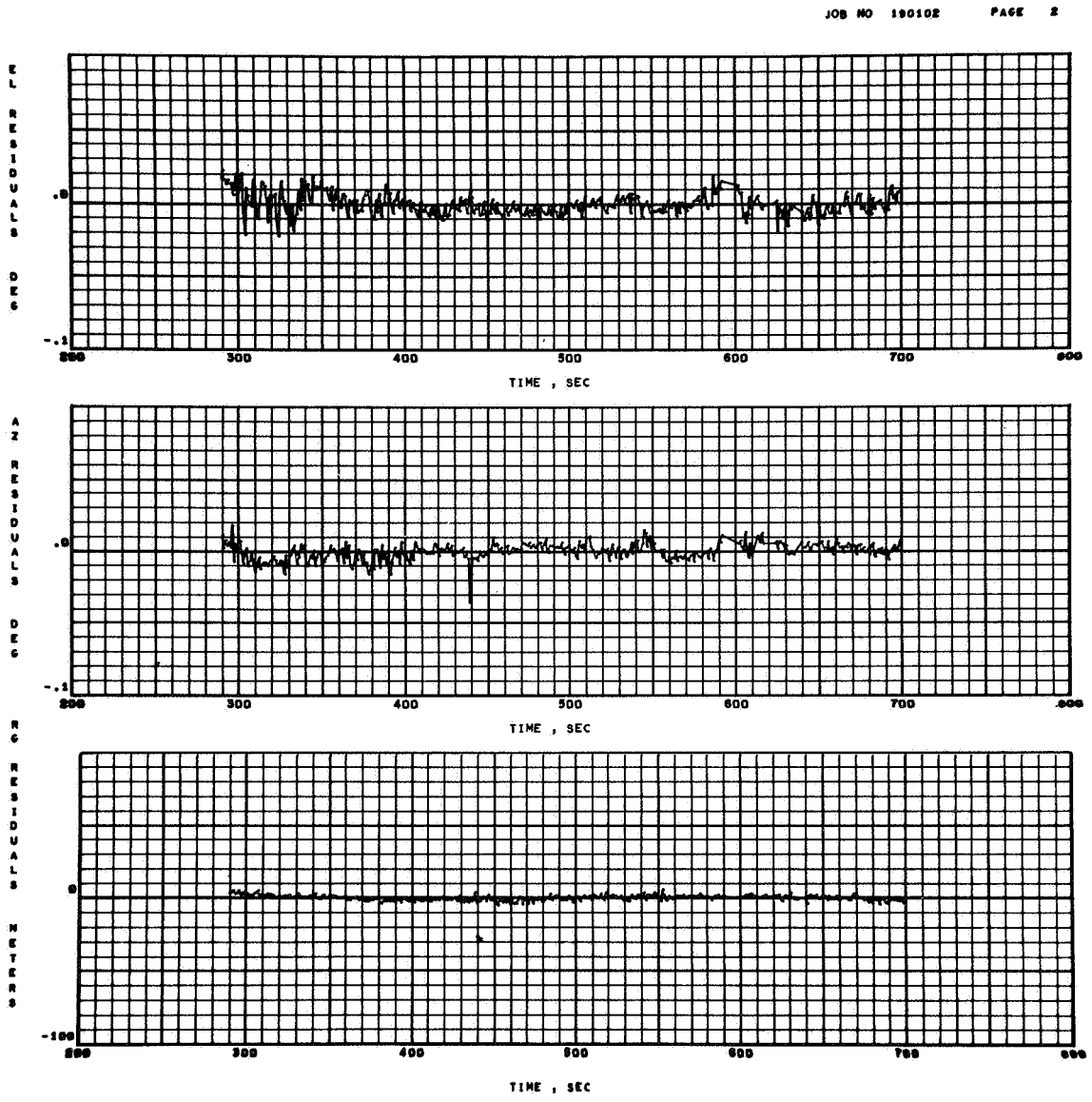

Figure A-9. Radar 67.16 residuals on AS-504 launch phase data.

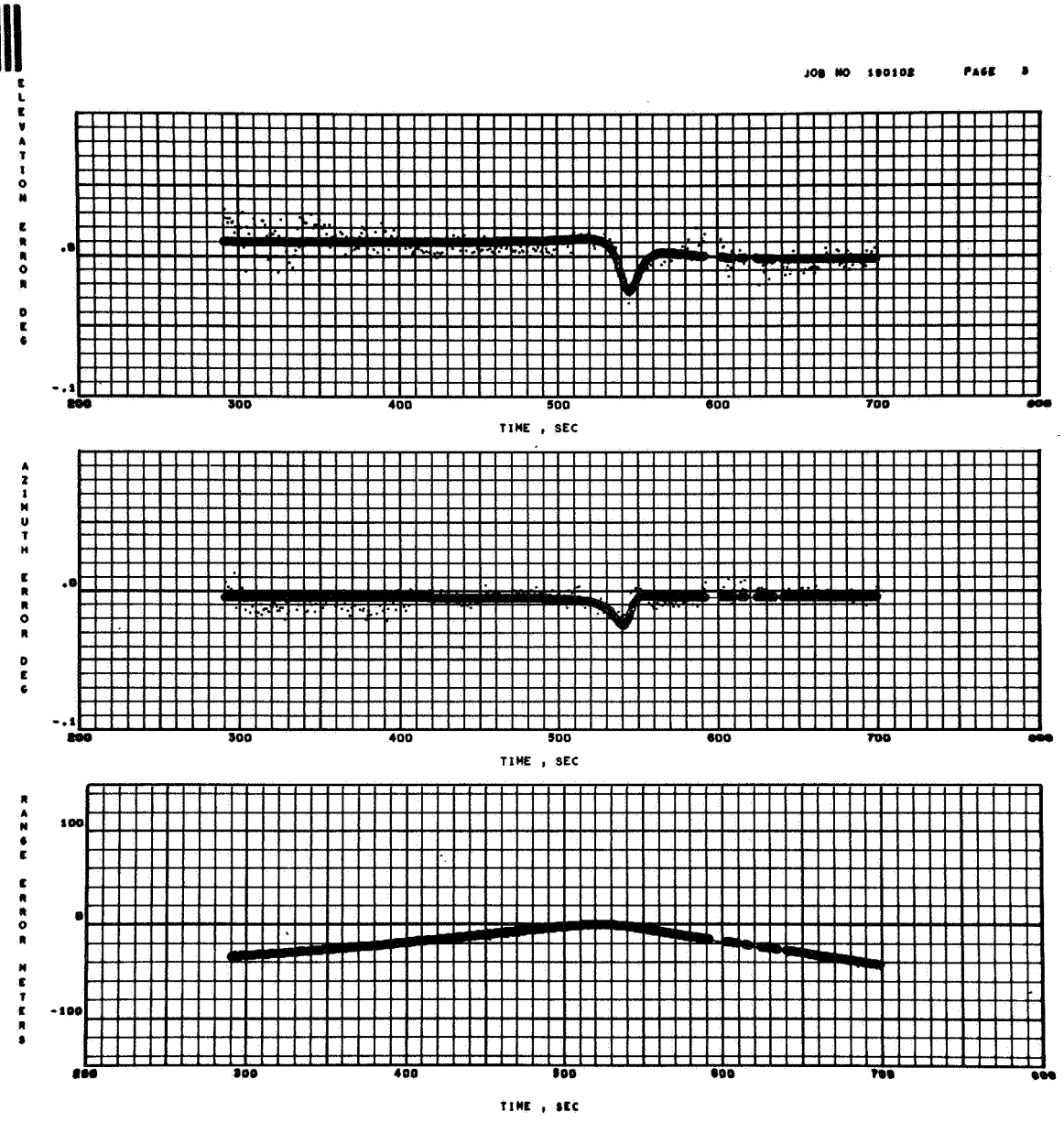

Figure A-10. Radar 67.16 range, azimuth, and elevation errors on AS-504 launch phase data

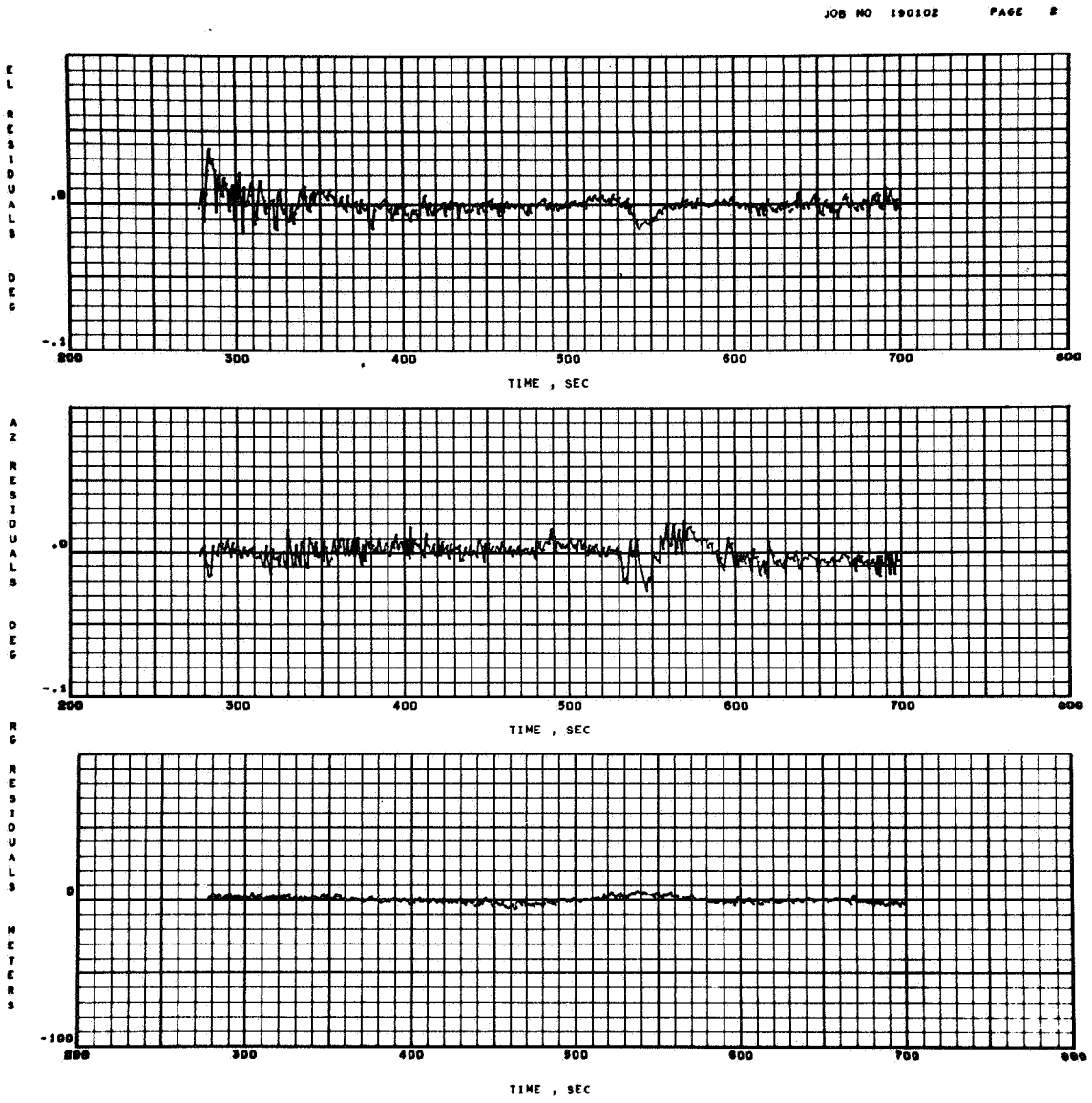

Figure A-11. Radar 67.18 residuals on AS-504 launch phase data.

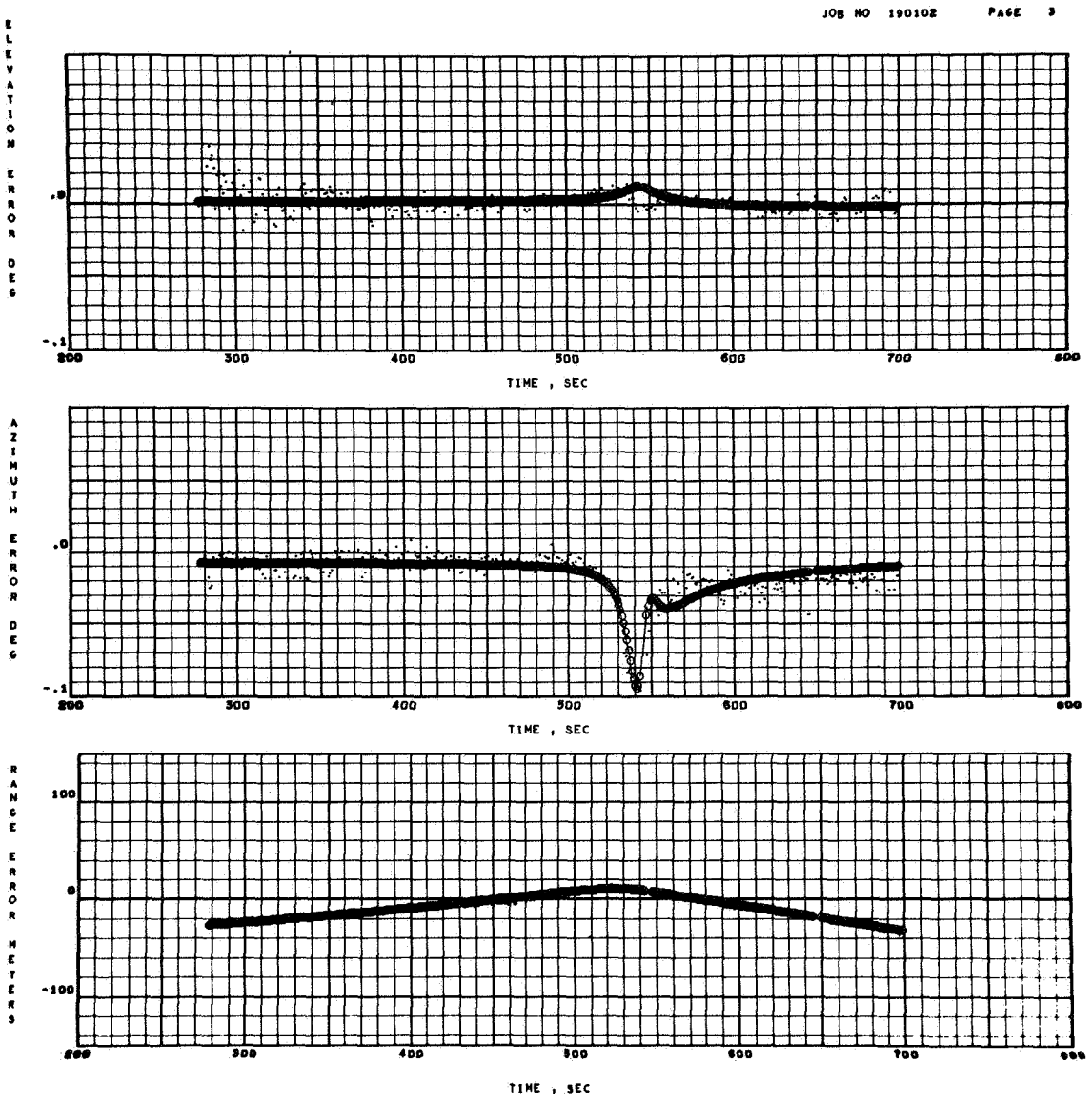

Figure A-12. Radar 67.18 range, azimuth, and elevation errors on AS-504 launch phase data.

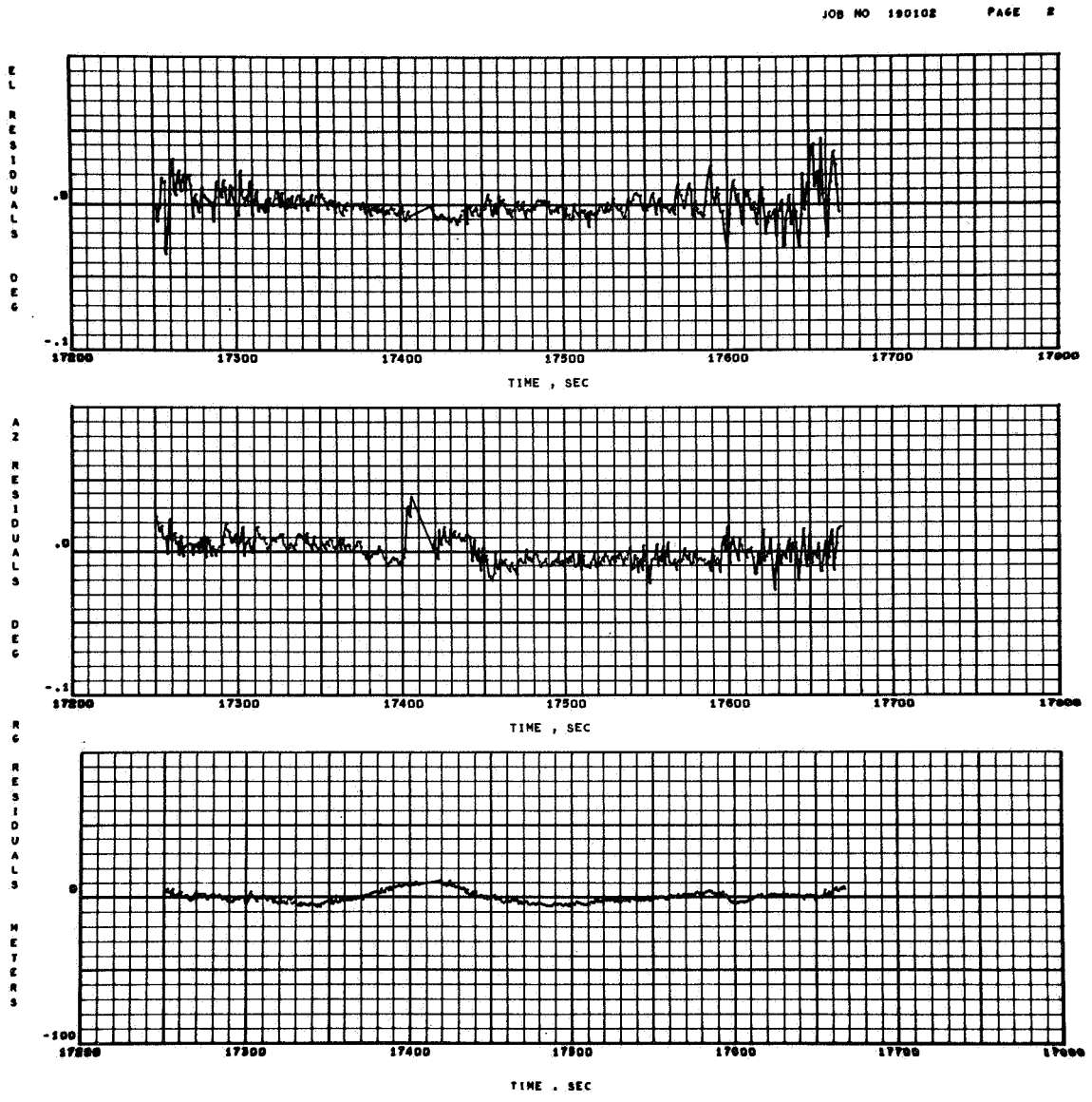

Figure A-13. Radar 91.18 residuals on AS-504 second burn data.

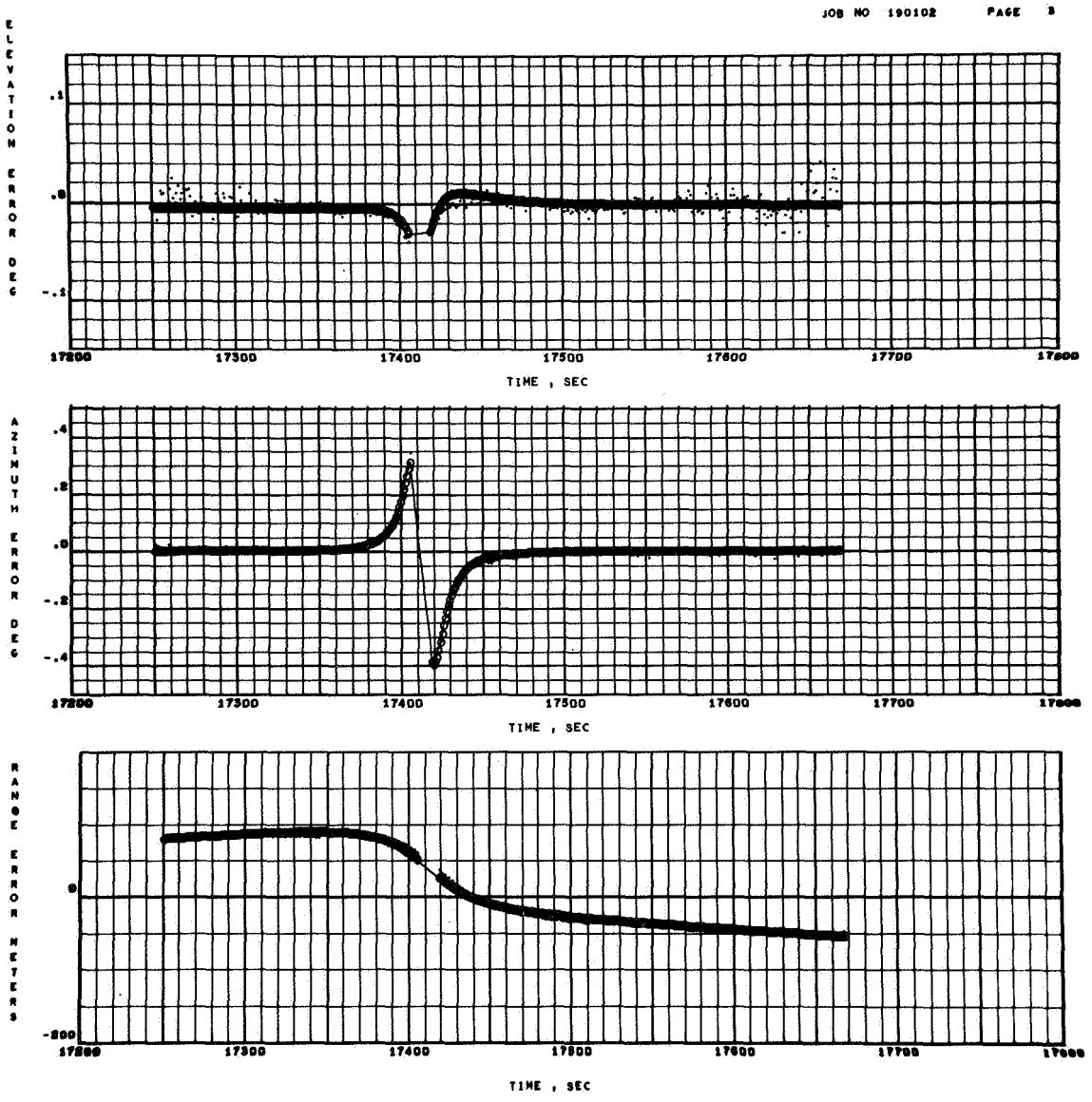

Figure A-14. Radar 91.18 range, azimuth, and elevation errors on AS-504 second burn data.

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APPROVAL

THE TEMS APOLLO-SATURN V TRACKING SYSTEM ERROR MODEL RESULTS THROUGH THE AS-504 FLIGHT TEST

By Bobby G. Junkin

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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